

Image Recognition Using Modified Zernike Moments

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Abstract: Zernike moments are complex moments with the orthogonal Zernike polynomials as kernel function, compared with other moments; Zernike moments have greater advantages in image rotation and low noise sensitivity. Because of the Zernike moments have image rotation invariance, and can construct arbitrary high order moments, it can be used for target recognition. In this paper, the Zernike moment algorithm is improved, which makes it having scale invariance in the processing of digital image. At last, an application of the improved Zernike moments in image recognition is given. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Zernike moments, Rotation invariance, Image recognition, Zernike polynomial, Normalization.

1. Introduction

Image recognition is a main branch in the field of pattern recognition; it is according to the image feature extracted from the image to classify the target [1]; the image feature generally including color, texture, shape, etc, at present the recognition technology based on the shape feature is the most widely used. In the two-dimensional image space, shape is generally considered to be the region surrounded by a closed contour curve, so the description of the shape involves contour boundary and the region surrounded by the boundary. The recognition methods based on shape mostly revolve round contour feature and regional feature of the shape. Descriptions of the shape contour feature mainly include: spline fitting curve, straight line segment description, Gaussian parameter curves and Fourier descriptor, etc. But these methods have limitations when being used, the descriptions of some shape features are not independent of the position, size and orientation of the shape, and they also lose a large amount of information, so the identification

effects are not ideal. Descriptions of the shape regional feature mainly include the area of the region, shape aspect ratio and shape invariance, etc. In 1961, M. K. Hu [2] proposed seven geometric invariant moments to measure the shape feature; it is a highly concentrated image feature, and not sensitive to the translation, rotation and scaling of the object, which plays a significant role in promoting the image recognition, after that researches on the moments had a rapid development, and successively appeared complex moments, rotation moments as well as other invariant moment analysis methods, the discovery of orthogonal moments is a big step of the moment technology, the orthogonal moments have proved to be better in terms of their strong ability to resist noise, good sampling performance, absolute independence, and no information redundancy; they are suitable for description and identification of the image. In 1979, M. R. Teague [3] proposed the Zernike moments based on the theory of orthogonal polynomials, they can be constructed easily into an arbitrary high order, and have good rotation invariance as well as simple calculation. C. H. Teh,

R. T. Chin [4] and A. Khotanzad [5] compared Zernike moments with many other moments, the results show that Zernike moments have the best performance in noise sensitivity, information redundancy, image description ability, etc.

2. Zernike Moments

2.1. Zernike Polynomials

In 1934, Zernike [6] proposed a set of orthogonal polynomials defined on the unit circle, namely orthogonal Zernike polynomials, their definition form is as follows:

$$V_{nm}(x, y) = V_{nm}(\rho, \theta) = R_{nm}(\rho)e^{jm\theta}, \quad (1)$$

$$R_{nm}(\rho) = \sum_{s=0}^{(n-|m|)/2} \frac{(-1)^s [(n-s)!] \rho^{n-2s}}{s! \left(\frac{n+|m|}{2} - s \right)! \left(\frac{n-|m|}{2} - s \right)!}, \quad (2)$$

where $R_{nm}(\rho)$ is the orthogonal radial polynomial, $V_{nm}(x, y)$ is the orthogonal Zernike polynomial, it is a set of complex-valued orthogonal functions with completeness defined over the unit disk $x^2 + y^2 \leq 1$, n and m are the orders of the orthogonal Zernike polynomials, where n is a positive integer or zero, m is a positive or negative integer, they are subject to the conditions $n - |m| = \text{even}$ and $n \geq |m|$ [7].

2.2. Definition of Zernike Moments

In 1980, based on the orthogonal Zernike polynomials, Teague proposed the definition of Zernike moments of an image function $f(x, y)$ in two dimensions for the first time [8].

$$Z_{nm} = \frac{n+1}{\pi} \iint_{x^2+y^2 \leq 1} f(x, y) V_{nm}^*(x, y) dx dy, \quad (3)$$

Zernike moments in polar coordinates can be defined as:

$$\begin{aligned} Z_{nm} &= \frac{n+1}{\pi} \int_0^{2\pi} \int_0^1 f(\rho, \theta) V_{nm}^*(\rho, \theta) \rho d\rho d\theta \\ &= \frac{n+1}{\pi} \int_0^{2\pi} \int_0^1 f(\rho, \theta) R_{nm}(\rho) \exp(-jm\theta) \rho d\rho d\theta \end{aligned}, \quad (4)$$

where $V_{nm}^*(\rho, \theta)$ is the complex conjugate of the Zernike polynomials $V_{nm}(\rho, \theta)$. Making the real and imaginary parts of Z_{nm} respectively denoted as C_{nm} and S_{nm} , then:

$$C_{nm} = \frac{2n+2}{\pi} \int_0^{2\pi} \int_0^1 R_{nm}(\rho) \cos(m\theta) f(\rho, \theta) \rho d\rho d\theta, \quad (5)$$

$$S_{nm} = \frac{2n+2}{\pi} \int_0^{2\pi} \int_0^1 R_{nm}(\rho) \sin(m\theta) f(\rho, \theta) \rho d\rho d\theta, \quad (6)$$

For digital images, the integrals are replaced by summations, and then the Zernike moments are rewritten as:

$$Z_{nm} = \frac{n+1}{\pi} \sum_x \sum_y f(x, y) V_{nm}^*(x, y), x^2 + y^2 \leq 1, \quad (7)$$

Because the images processed in practical application are usually digital images, the real and imaginary parts of their Zernike moments need to be discretized. Mukundan and Ramakrishnan proposed the following transformation [9]: for any image $f(x, y)$ of size $N \times N$, making its coordinate origin located at the center of the image, then $-N/2 \leq x, y \leq N/2$. For pixel (x, y) , introducing two parameters η and σ correspond to the pixel uniquely, it is defined as:

$$\eta = \max(|x|, |y|), \quad (8)$$

If $\eta = |x|$, then $\sigma = 2(\eta - x)y / |y| + xy / \eta$.

If $\eta = |y|$, then $\sigma = 2y - xy / \eta$.

From the formula we can see, the value of η is from 1 to $N/2$, the value of σ is from 1 to 8η , by the parameters η and σ we can define the corresponding polar coordinates as follows:

$$\rho = 2\eta / N, \quad \theta = \pi\sigma / 4\eta, \quad (9)$$

Through the above transformation, the real and imaginary parts of the Zernike moments Z_{nm} can be written in the discrete form as follows:

$$C_{nm} = \frac{2N+2}{N^2} \sum_{\eta=1}^{N/2} R_{nm}(2\eta/N) \sum_{\sigma=1}^{8\eta} \cos \frac{\pi m \sigma}{4\eta} f(\eta, \sigma), \quad (10)$$

$$S_{nm} = \frac{2N+2}{N^2} \sum_{\eta=1}^{N/2} R_{nm}(2\eta/N) \sum_{\sigma=1}^{8\eta} \sin \frac{\pi m \sigma}{4\eta} f(\eta, \sigma), \quad (11)$$

2.3. Invariance of Zernike Moments

Zernike moments are region-based shape descriptors, and their bases are the orthogonal radial polynomials, compared with other shape descriptors, Zernike moments have better rotation invariance [10].

If an image is rotated through angle α , according to the definition of Zernike moments, the

relationship between the Zernike moments of the rotated image Z_{nm}^* and the original one Z_{nm} is:

$$Z_{nm}^* = Z_{nm} e(-jm\alpha), \quad (12)$$

From the formula we can see, the Zernike moments before and after the image rotation only have phase changes, their magnitudes remain unchanged, so the magnitude $|Z_{nm}|$ of the Zernike moments can be taken as a rotation invariant feature of the target [11].

3. Improved Zernike Moments

In the discrete case, because the rotation and scale transformation will cause the resampling and requantization of digital image, thereby causing certain error, which will makes its invariance not keep strictly invariant. Therefore considering first to carry on shape normalization to the target area of the image, and then normalize the Zernike moments, in order to get a better rotation and scale invariance [12].

The steps are as follows:

1) Preprocess the image: using median filter to remove the noise and retain the image's edge detail, turning the true color image into grayscale image of 256 levels, selecting the appropriate threshold for binarization processing and then doing negated operation, so that the target image and the background are separated; thereafter the target image is converted to the unit circle in polar coordinates, that is taking the barycenter of the image as the center of the polar coordinates, and then taking the distance between the center and the outermost pixel in the target area as the radius, thus the pixels in the target area are resampled to the unit circle.

2) Calculate the zeroth order geometric moment of the target, namely:

$$m_{00} = \sum \sum f(x, y), \quad (13)$$

3) Calculate each order of the Zernike moments in the unit circle:

$$Z_{nm} = \frac{n+1}{\pi} \sum_x \sum_y f(x, y) V_{nm}^*(x, y), \quad (14)$$

4) Use m_{00} to normalize the Zernike moments:

$$Z'_{nm} = \frac{Z_{nm}}{m_{00}}, \quad (15)$$

5) Evaluate the magnitudes $|Z'_{nm}|$ of Z'_{nm} as the invariant feature of the target's improved moments.

Next testing the improved Zernike moments, taking the following Fig. 1 for example.



Fig. 1. The example image.

Preprocessing the image first; then rotating the image by 30° , 60° , 90° and 135° ; at last calculating the improved Zernike moments of the rotated images, Table 1 shows the results:

Scaling Fig. 1 by 0.2 times, 0.8 times, 2 times and 4 times, and then calculating the improved Zernike

Moments of these scaled images, the results are represented in Table 2.

For the sake of comparison, calculating the original Zernike moments of the scaled images, the results are shown in Table 3.

Table 1. Improved Zernike moments of the rotated images.

Rotated degree Feature	0°	30°	60°	90°	135°
$ Z'_{20} $	0.4903	0.4904	0.4904	0.4903	0.4899
$ Z'_{22} $	0.0592	0.0592	0.0592	0.0592	0.0593
$ Z'_{31} $	0.0895	0.0894	0.0894	0.0895	0.0893
$ Z'_{33} $	0.0331	0.0330	0.0330	0.0331	0.0332
$ Z'_{40} $	0.1713	0.1717	0.1717	0.1713	0.1709
$ Z'_{42} $	0.1507	0.1507	0.1508	0.1507	0.1508
$ Z'_{44} $	0.0805	0.0805	0.0804	0.0805	0.0806

Table 2. Improved Zernike moments of the scaled images.

Scaled times Feature	0.2	0.8	1	2	4
$ Z'_{20} $	0.4649	0.4888	0.4903	0.4934	0.4950
$ Z'_{22} $	0.0624	0.0594	0.0592	0.0588	0.0586
$ Z'_{31} $	0.0916	0.0897	0.0895	0.0892	0.0891
$ Z'_{33} $	0.0350	0.0332	0.0331	0.0328	0.0326
$ Z'_{40} $	0.1450	0.1696	0.1713	0.1748	0.1766
$ Z'_{42} $	0.1506	0.1507	0.1507	0.1507	0.1506
$ Z'_{44} $	0.0887	0.0811	0.0805	0.0794	0.0789

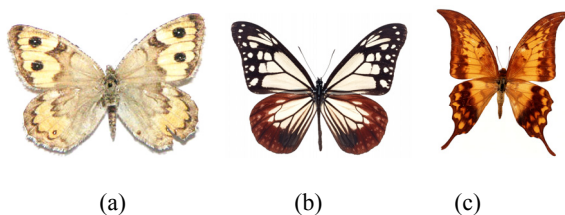
Table 3. Zernike moments of the scaled images.

Times Feature	0.2	0.8	1	2	4
$ Z_{20} $	92.3278	1553.1	2434.4	9799.3	39320
$ Z_{22} $	12.4000	188.7619	294.0115	1168.2	4657.2
$ Z_{31} $	18.1891	284.9703	444.3653	1771.8	7075.7
$ Z_{33} $	6.9424	105.6076	164.2716	650.6338	2589.3
$ Z_{40} $	28.8039	539.0052	850.7314	3472.4	1403.0
$ Z_{42} $	29.9081	478.8410	748.2657	2992.1	11966
$ Z_{44} $	17.6094	257.5578	399.6595	1577.5	6267.7

Through the experimental data, we can find that the improved Zernike moments have good rotation invariant features, the moment values of the rotated images of the same kind are very close, for the scaled images, in addition to the change of the moment values are larger when they are scaled by smaller multiples, in other cases, the deviation is small, compared with the original Zernike moments, the modified moments have certain scale invariance, thus proving their feasibility.

4. Application

Next, we will introduce the application of improved Zernike moments in image recognition, assuming that there are the following three kinds of butterfly images in the image library:

**Fig. 2.** Three standard images in the library.

Doing some rotation and scale transforms to the images, calculating their each order Zernike moment Z_{nm} according to the definition of Zernike moments, and conducting the normalized processing to Z_{nm} using the improved moment method proposed in this paper, then evaluating their magnitudes, we will get a new feature vector $|Z'_{nm}|$, after that averaging the feature vector of the image of the same kind and using the obtained feature value represents it.

Afterwards we use the block distance method to recognize the image to be identified. Block distance is defined as: supposing $P1$ and $P2$ are two pixels of a given image, their position coordinates in the image respectively are $(x1, y1)$, $(x2, y2)$, assuming that D is a distance measure function, then the block distance between $P1$ and $P2$ is $D(P1, P2) = |x1 - x2| + |y1 - y2|$ [13]. According to the formula, calculating the block distance between the feature values of the target to be identified and each kind of the known targets, the target to be identified belongs to the one having the minimum calculation result.

According to the above method to identify 15 of these three kinds of images, from the result we can see: the recognition rate of some order of the improved Zernike moments can reach one hundred percent, to the other order, even if it can't correctly

identify all of the targets, its recognition rate is relatively high.

5. Conclusion

The improved Zernike moments introduced in the paper not only have rotation invariant feature, but also have certain scale invariance compared with the original Zernike moments, but they still exist shortcomings, namely when the scaling times of the image are smaller, the deviation of the resulting improved Zernike moment values are relatively large, which results in certain recognition errors, in order to have widespread use we need to improve them by further researches.

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